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A Method of Estimating Reduction in Yield of Wheat Caused by Hessian Fly Infestation

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INTRODUCTION

Since the publication in 1925 of a preliminary study of the relation of damage caused by the hessian fly (*Phytophaga destructor* (Say)) to yield,[3] further investigations have been made which serve to revise and supplement the previous findings. These recent studies also furnish sufficient basic data to make it possible to estimate with reasonable accuracy the damage sustained by the wheat crop as indicated by the percentage of hessian fly infestation of the spring generation observed in the standing wheat.

Two methods of approach to this problem were employed. The first presented data on the amount of loss incurred from the diminished development of the grain in the individual head due to the presence of the fly in the culm. This furnished the data from which table 3 was devised, intended to facilitate a rapid calculation of such losses.

The second method, in which field cages were used, was undertaken to substantiate and to some extent supplement these results. It took into consideration the entire effects of the spring infestation

[1] Mr. Pinckney died December 12, 1940.

[2] The authors acknowledge their indebtedness to C. M. Packard, under whose general supervision the work was done; to F. M. Wadley and W. B. Cartwright for helpful criticisms; and to H. D. Smith for many of the original observations.

[3] Hill, C. C., and Smith, H. D. The relation of hessian fly damage to yield. Jour. Econ. Ent. 18: 69–73. 1925.

of the fly in reducing yield, which included, in addition to the type of loss above mentioned, such factors as lodging of the standing grain and the complete stunting of the wheat culm.

RELATION BETWEEN WEIGHT OF GRAIN IN HEAD AND NUMBER OF PUPARIA IN CULM

Samples of wheat plants were collected at harvesttime from different fields of soft red winter wheat during certain years from 1918 to 1939, inclusive. The individual culms from each sample were examined

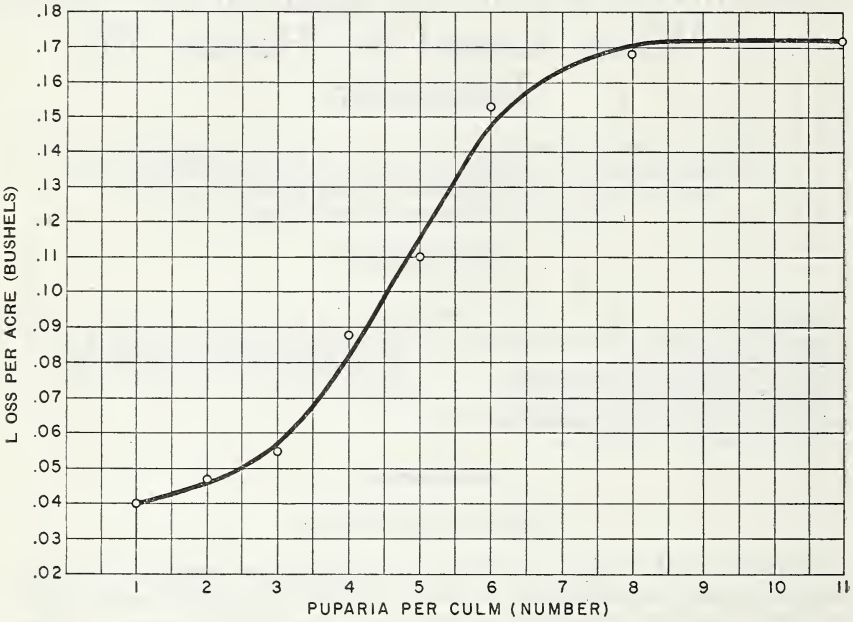

FIGURE 1.—Relationship between the number of hessian fly puparia per wheat culm and loss in yield of grain when 1 percent of the culms is infested.

for hessian fly infestation, and the heads from these culms were separated into lots according to the number of hessian fly puparia lodged in the respective culms. The grain was removed and weighed, and the average weight per head per lot was ascertained. The results from 13 different fields are shown in table 1. In converting grams per head to bushels per acre the number of 1,321,000 culms per acre was used as a basis for calculation. The method of obtaining this figure will be described later. Table 1 shows the shrinkage in weight per head coincident with each additional puparium present in the culm. This shrinkage is shown in figure 1 as loss in bushels per acre when 1 percent of the culms is infested. It will be observed that the increase in loss above 6 puparia per culm rapidly lessens until no increase shows. This might be anticipated because of the probability that those culms that succeeded in producing any heads at all under the handicap of such heavy infestations were those which were exceptionally hardy and consequently showed proportionately

TABLE 1.—*Wheat heads and average weight of grain per head when the culms were infested with various numbers of puparia of the hessian fly*

Year	Locality	No puparia		1 puparium		2 puparia		3 puparia		4 puparia		5 puparia		6 puparia		7 to 9 puparia		10 to 12 puparia	
		Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain	Wheat heads	Average weight of grain
		Number	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*	*Number*	*Grams*
1918	Mount Holly Springs, Pa	130	0.739	130	0.652	41	0.679	18	0.647	6	0.550								
1919	Do	100	.454	98	.324	20	.300	7	.307	5	.230								
1919	Carlisle, Pa	940	.309	300	.261	128	.227	46	.300	27	.207	14	0.196						
1923	Lewisburg, Pa	490	.752	99	.644	81	.694	52	.731	31	.610	14	.571	3	0.400	14	0.514	4	0.475
1924	Bloomsburg, Pa., Field No. 1	126	.656	125	.573	75	.587	74	.565	35	.521	28	.427	17	.344	18	.262	3	.300
1924	Bloomsburg, Pa., Field No. 2	92	.678	99	.586	75	.534	74	.505	69	.410	37	.373	26	.273	38	.268	7	.250
1924	Bloomsburg, Pa., Field No. 3	245	.490	104	.388	41	.352	11	.336	5	.300								
1929	Gretna, Va	109	.430	17	.282	7	.257	5	.240	6	.133	4	.175	2	.150				
1930	Do	70	.442	40	.387	30	.372	19	.349	17	.255	3	.241	9	.164				
1930	Mercer, Pa	149	.400	61	.381	21	.373	8	.244	5	.362								
1932	Bedford, Pa	137	.443	85	.360	60	.353	33	.333	24	.250	6	.205	16	.180				
1934	Indiana, Pa	107	.579	61	.521	40	.470	22	.422	1	.320	5	.286						
1939	Osgood, Pa	107	.483	46	.417	22	.411	12	.397	3	.351								
	Total number of heads	2,802		1,265		641		381		234		111		73		70		14	
	Average loss in weight per head—grams				.083		.096		.114		.181		.227		.315		.347		.354
	Average loss per acre at 1 percent infestation [1] bushels				.040		.047		.055		.088		.110		.153		.168		.172

[1] At the rate of 1,321,000 culms per acre.

less effects of the damage. As a matter of fact, under conditions of heavy infestation the weaker culms become so stunted that they fail entirely to produce heads and consequently cannot be considered in these calculations.

NUMBER OF PRODUCTIVE WHEAT CULMS PER ACRE

To convert the loss in weight per infested head into terms of bushels per acre it became necessary to estimate the average number of productive wheat culms per acre in a typical wheatfield. The basis of this average was 6 measured linear-foot samples of mature wheat plants taken at random during the years from 1918 to 1937, inclusive, from each of 370 fields distributed over New York, New Jersey, Pennsylvania, Maryland, Virginia, West Virginia, and North Carolina, and ranging from Niagara County, N. Y., on the north to Rowan County, N. C., on the south. Of these fields, 253 had been sown with 8-inch drills and 117 with 7-inch drills. The difference in spacing was taken into account in the calculations. From these records the number of productive culms per acre averaged 1,321,000. This figure has been used in the calculations involving acre yields.

RELATION BETWEEN PERCENTAGE OF WHEAT CULMS INFESTED AND NUMBER OF PUPARIA PER CULM

The number of puparia per culm, or intensity of infestation, varies in a wheatfield with the percentage of wheat culms infested. To estimate definitely the loss for any given infestation it was necessary to place this relationship on a numerical basis. A total of 1,409 records were therefore made during the years 1915 to 1933, inclusive, representing 327 localities distributed over the 7 States previously mentioned. These observations included wheatfields showing degrees of infestation of from 1 to 97 percent of the culms. Table 2 gives the average number of hessian fly puparia per infested culm for each 10-percent range of culm infestation from 1 to 80 percent, and for a 20-percent range between 81 and 100 percent. The aggregate number of records for each group is also shown. A graph of these data is given in figure 2, which shows the acceleration in number of puparia per culm caused by the increase in infestation.

TABLE 2.—*Number of hessian fly puparia per culm in relation to the percentage of infestation in a wheatfield together with the aggregate number of records for each group as shown*

Percentage of culms infested	Records	Average hessian fly puparia per infested culm
	Number	*Number*
1 to 10	685	1.3
11 to 20	285	1.4
21 to 30	135	1.5
31 to 40	112	1.7
41 to 50	72	2.0
51 to 60	39	2.2
61 to 70	43	2.7
71 to 80	23	3.1
81 to 100	15	4.7

It would be possible for the number of puparia per culm to increase beyond the number calculated for the point where 100 percent of the culms were infested. However, such high infestation by the spring generation of the fly is rare and has never been witnessed by the writers. The attempt to calculate theoretical losses from such severe infestations is therefore considered unnecessary.

LOSS IN YIELD OF GRAIN PER ACRE RESULTING FROM ANY GIVEN DEGREE OF INFESTATION

To estimate loss in yield of wheat per acre for any given infestation of the hessian fly it was necessary to combine data taken from figures

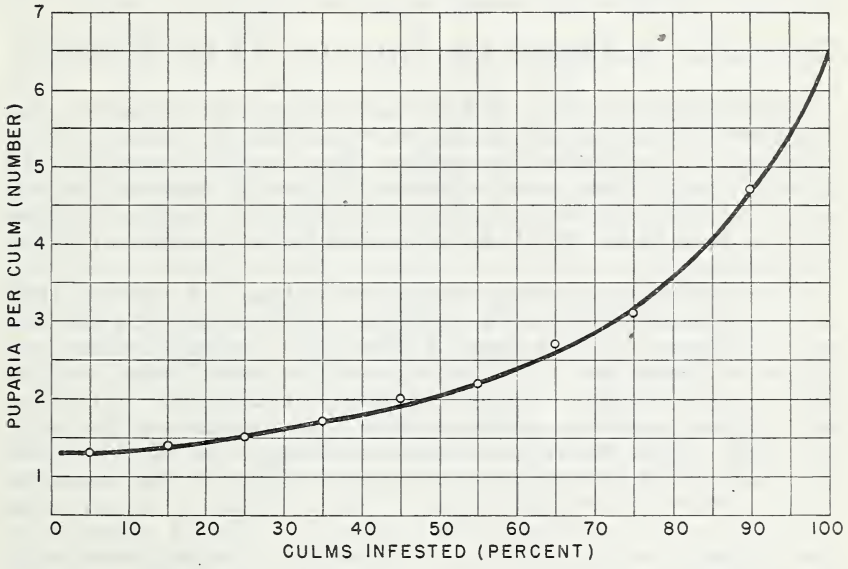

FIGURE 2.—Relation of number of hessian fly puparia per infested wheat culm to the percentage of culms infested based on 1,409 observations averaged by groups of 10 percent. (The range from 81 percent to 100 percent has been used as a unit owing to the small number of records within this category.)

1 and 2. This has been done in table 3. The losses in bushels per acre were derived by the use of the relationship shown in figures 1 and 2. In table 3 the top marginal figures represent units, and the left-side marginal figures represent tens, in percentages of culms infested. From this table the loss to the standing grain may be estimated for any given infestation of the hessian fly by the spring generation in an ordinary wheatfield. For instance, a 56-percent infestation shows a loss of 2.63 bushels per acre.

In the use of this table the question has arisen as to whether the values given are equally applicable to high-yielding and low-yielding fields. On this point, so far as could be determined from the data used in these studies, the actual loss in yield caused by the hessian fly, although of course not the percentage of loss, was not appreciably affected by other factors causing greater or less yield.

TABLE 3.—*Estimated loss in yield of wheat, in bushels per acre, due to any given percentage of culms infested by the spring generation of the hessian fly*

Percentage (by tens) of culms infested	Unit percentage of culms infested (to be added to figures in stub)									
	0	1	2	3	4	5	6	7	8	9
	Bushel	*Bushel*	*Bushel*	*Bushel*	*Bushel*	*Bushel*	*Bushel*	*Bushel*	*Bushel*	*Bushel*
0	-------	0.04	0.08	0.12	0.16	0.20	0.25	0.29	0.33	0.37
10	0.41	.45	.49	.53	.59	.63	.67	.71	.76	.80
20	.84	.88	.95	.99	1.03	1.08	1.12	1.16	1.20	1.25
30	1.29	1.33	1.38	1.45	1.50	1.54	1.58	1.63	1.67	1.72
40	1.76	1.80	1.85	1.93	1.98	2.03	2.07	2.16	2.21	2.25
50	2.30	2.35	2.39	2.44	2.54	2.59	2.63	2.74	2.78	2.89
60	2.94	2.99	3.10	3.15	3.33	3.38	3.50	3.55	3.67	3.73
70	3.92	3.98	4.18	4.23	4.37	4.57	4.64	4.93	5.15	5.37
80	5.68	5.91	5.99	6.31	6.97	7.31	7.65	8.00	8.45	8.81
90	9.45	9.92	10.58	11.07	11.75	12.16	12.96	13.77	14.41	15.05
100	15.70	-------	-------	-------	-------	-------	-------	-------	-------	-------

SELECTIVE ACTIVITY OF THE FLY AT OVIPOSITION

Consideration was given to the chance of error in calculation due to the possible tendency of females to oviposit on the weaker, shorter culms which would normally produce lighter-weight heads whether infested or not. Some observations were therefore made to discover the actual difference in the height of infested and uninfested culms from the base to the tip of the uppermost leaf at the time of spring oviposition.

A series of 500 observations were made on April 1, 2, and 3 in 1930 in a wheatfield in Gretna, Va. Of these 265 bore eggs and the rest were uninfested. The average height of the infested culms was 6.24 ± 0.10 inches and of the uninfested 6.31 ± 0.12 inches, with a difference of 0.07 inch. On April 18, 1941, in Carlisle, Pa., during the peak of the oviposition period, similar observations were made on 286 culms, 189 of which were infested with eggs and 97 uninfested. The height of the infested culms averaged 8.97 ± 0.15 inches and that of the uninfested 9.94 ± 0.24 inches, with a difference of 0.97 inch. Although both these experiments showed the infested culms to be shorter than those not infested, the difference in height is obviously not significant.

Another slightly different experiment was conducted in April 1930 in a wheatfield in Gretna, Va., in which the heights of 110 wheat culms were measured at the time of fly oviposition and each culm staked for future observations relative to infestation and productivity. At harvesttime only those culms that produced heads were taken into consideration. Of these 15 were found infested with hessian fly puparia and 29 were uninfested. The record of their heights during the fly oviposition period showed that the infested culms averaged 7.10 ± 0.37 inches and the uninfested culms 7.03 ± 0.30 inches with a difference of 0.07 inch in favor of the infested culms. This experiment, by giving consideration only to those culms that produced heads, conformed with the basic experiments to determine the relation between infestation and yield, as already discussed. This experiment thus furnishes a truer picture of fly selectivity as it might affect the type of culm used in those calculations.

These various observations lead to the conclusion that any preference which the flies may show for selecting the weaker rather than the stronger plants on which to ovipost during the spring may be

considered of negligible significance in the calculations presented in this circular.

CAGE EXPERIMENTS TO DETERMINE THE FULL EFFECTS ON YIELD OF INFESTATIONS BY THE SPRING GENERATION OF THE FLY

A further test to determine the reduction in yield of wheat due to the spring generation of the hessian fly was conducted by means of cages. For this purpose three cages of uniform design were constructed. They consisted of a light wooden frame 8 by 8 by 6 feet, covered on sides and top with loosely woven muslin cloth reinforced at the corners to prevent tearing. A cord network was fastened around the outside to strengthen the cloth against the wind and guy wires held the cages in place.

The cages were set out on April 17, 1934, before fly activity had begun. They were placed several yards apart on a level, uniform area in a field of Rudy wheat near Carlisle, Pa., which examination showed to be apparently free from hessian fly infestation. Cage 1 was allowed to remain as nearly uninfested as possible. A considerable number of hessian fly puparia were placed in cage 2 and a much larger number in cage 3. Fly adults were also released later in both cages 2 and 3 to augment the infestation. On May 23, after fly activity had ceased in the field, the cloth coverings were removed from the cages. The wheat culms that had been enclosed in the cages were slightly taller than those of the surrounding field but otherwise appeared to have a normal growth. When the field was ready to harvest in July, a square yard of wheat plants, including all the culms with roots and heads, was carefully removed from each of the plots that had been caged. The results of detailed examination of these samples are shown in table 4. It was found that a light infestation of the fly had developed in cage 1, though not enough to interfere with the experiment.

TABLE 4.—*Analysis of wheat plants from 1 square yard removed at harvesttime from each of 3 cages variously infested with the hessian fly, Carlisle, Pa., 1934*

	Cage 1	Cage 2	Cage 3
Total culms—number	329	378	346
Total nonproductive culms—do	36	86	66
Nonproductive culms infested—do	1	45	32
Culms infested—percent	7.90	29.10	47.69
Weight of grain per wheat head—grams	.873	.836	.778
Yield per acre—bushels	42.38	40.58	37.76
Increase of infestation over cage 1—percent		21.20	39.79
Reduction in yield as compared with cage 1—bushels		1.80	4.62

From table 4 it may be observed that in cage 2 an increase of infestation of 21.20 percent over cage 1 resulted in a reduction in weight of grain of 1.80 bushels per acre. In cage 3 an increase of infestation of 39.79 percent over cage 1 resulted in a reduction in weight of grain of 4.62 bushels per acre. Comparing these figures with those shown in table 3, 21.20 percent infestation in the table corresponds to a loss of approximately 0.88 bushel, as compared with a loss of 1.80 bushels in the cages, and 39.79 percent infestation in the table would call for

a loss of approximately 1.76 bushels as compared with 4.62 bushels in the cages.

The heavier losses shown by the cage records were anticipated because of the fact that the figures in table 3, as already explained, indicate losses due only to a reduction in weight of the grain, whereas results of the cage experiments include additional loss caused by the fly. Some of this additional loss can be attributed to such severe stunting of some of the culms by the flies that no heads developed on them. By comparing the results from cages 2 and 3 with those from cage 1 it may be seen that the additional infestations in both cages 2 and 3 were accompanied by greatly increased numbers of nonproductive culms.

All the figures as given in table 4 are not closely comparable between cages because of varying numbers of culms in the square-yard samples. The following corrections have therefore been made on the basis of ratio and proportion:

Total number of nonproductive culms----	Cage 1, 36; cage 2, 75; cage 3, 63.
Number of nonproductive culms infested_	Cage 1, 1; cage 2, 39; cage 3, 31.

By subtracting the one infested nonproductive culm in cage 1 from the 36 nonproductive culms in that cage, there remain 35 nonproductive culms uninfested. It is reasonable to believe that this number would have been approximately the same in cages 2 and 3 but for some modifying factor in the latter cages not present in cage 1. The greater hessian fly infestation in these cages may be considered such a factor, the effect of which may be measured by the 39 infested nonproductive culms in cage 2 and the 31 in cage 3. If these numbers, 39 and 31, be subtracted from the total nonproductive culms found in their respective cages, the remainders are 36 in cage 2 and 32 in cage 3, which might be considered as approximating the number of 35 found in cage 1 where insignificant infestation of nonproductive culms occurred. From these figures it seems reasonable to infer that hessian fly infestations serve considerably to reduce the yield by stunting wheat culms to the point of entire nonproductivity.

Another loss in addition to that estimated in table 3 is due to the breaking over, or lodging of stem and shattering of grain caused by the hessian fly.

The cage experiments demonstrate that considerably more loss may be expected to occur from hessian fly attacks than that involved solely in the reduced development of the grain, and they definitely prove that the figures given in table 3 are very conservative. This additional loss, while it should be recognized, would for the most part be difficult if not impossible to correlate closely with given amounts of infestation, because of the variable effects of many other factors, such as weather conditions, time of harvesting, and variety of wheat which influence the lodging and consequent shattering of grain in infested fields.

In conclusion, it would appear justifiable to consider table 3 as a reliable, although conservative, gauge for correlating the amount of infestation with loss of weight in the standing grain due to hessian fly damage.

SUMMARY

The results are presented of a study to determine the losses in yield of wheat due to different degrees of infestation by the hessian fly during the spring growing season.

An analysis was made of 13 wheatfields from New York to North Carolina in which the relationship was ascertained between the number of hessian fly puparia in the culm and the weight of grain per head with the consequent loss in yield in bushels per acre resulting from any given degree of infestation. Intermediate steps required the calculation of the approximate number of productive wheat culms to be found per acre.

Investigation of the possibility that a selective activity of the fly at time of oviposition might have a modifying effect on the results of these deductions showed this factor to be negligible.

Experiments were also conducted under cages in which the degree of hessian fly infestation was controlled. Results of these experiments demonstrated that the hessian fly may cause considerably more loss than that due solely to the lessened development of the grain. Thus estimates of losses which include only those due to that factor are considered very conservative.

From the assembled data a table was prepared showing the losses of grain in bushels per acre resulting from different percentages of productive culms infested by the hessian fly in the spring. According to this table the losses range from 0.04 bushel per acre when only 1 percent of the productive culms are infested to 15.7 bushels per acre when 100 percent of the productive culms are infested.

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